Simulations of contrail-to-cirrus transition: Study of the radiative impact on contrail evolution

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Personal Introduction

Simon Unterstrasser

- Currently Post-Doc position at DLR, Oberpfaffenhofen (since 01/2009)
- From 09/2006 to 12/2008 PhD at DLR-IPA
- Title: “Numerical simulations of contrails and their transition to cirrus” (in german, supervisors U. Schumann and B. Kärcher)

Motivation

- The climatic impact of contrail-cirrus only vaguely known (Lee et al., 2009; Sausen et al., 2005; IPCC, 2007)
- Discrimination from natural cirrus difficult (in-situ and in satellite imagery)
- Poor knowledge on contrail-cirrus

Presence & Future

- Model-based approach to finally obtain RF of contrail-cirrus
- In models cirrus and contrail-cirrus distinguishable
- LES-model simulates contrail-to-cirrus transition in detail
- Parameterization of contrail life cycle in GCM (Burkhardt & Kärcher, JGR 2009, accepted)

LES-Model for contrail-cirrus simulations

- Basic model: EULAG (Smolarkiewicz & Margolin, 1997,1998)
- Ice microphysics: 2-moment bulk scheme with lognormal ice crystal size distribution (Spichtinger & Gierens, 2009)
- Radiation routine with independent column approximation (Fu & Liou, 1993, Fu et al., 1998)
- Initialization with realistic contrails (2 - 3 min old) using results from vortex-phase simulations (Unterstrasser et al., 2008)

Study the evolution of

- microphysical properties
- geometric properties
- optical properties

Study the impact of

- relative humidity
- temperature
- vertical wind shear

Selected findings on the Poster (last chance !)

Radiation-induced dynamics

- Radiative heating/cooling leads to contrail lifting/sinking
- A radiatively heated contrail cools adiabatically
- The saturation pressure changes and the contrail ice mass changes accordingly
- Affects the contrails micro- and macrophysical properties
- The vertical displacement depends on the heating rate and the atmospheric stratification N_{BV}

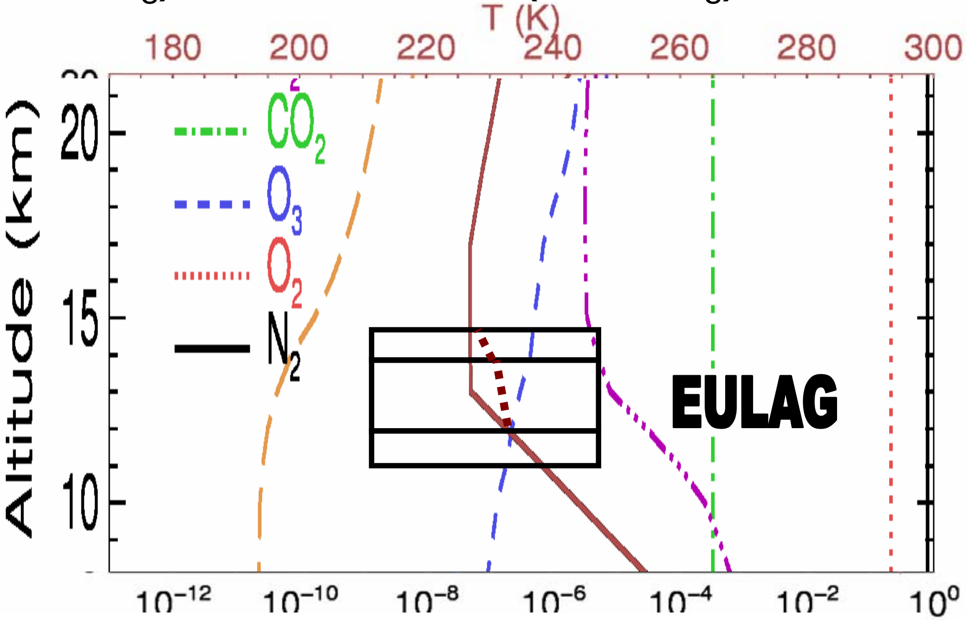
Coupling of the basic model with the radiation routine

Input of the radiation routine

T(z), p(z), [NO_2, CO_2, N_2O, CH_4, H_2O](z), T_{sfc}, $Albedo_{sfc}$,
solar zenith angle, ice clouds (IWC, r_e), water clouds (LWC, r_e)

Anderson et al, 1986 provide vertical profiles for various seasons and latitudes, z = 0 - 120km

Shift the EULAG domain to an adequate height in the UTLS region use the EULAG values in this layer



Output: Heating rates act as diabetic term in EULAG thermodynamic equation

Sensitivity study of the radiative impact

Study the sensitivity of the contrail properties on the …

… radiation scenario

Determined by season, time of day and lower-level cloud

Season	Summer or winter	Characteristic profiles (Anderson,1986)
Time of day	Day or night	Solar zenith angle 45° or 90°
Lower-level cloud	Yes or No	Yes or No

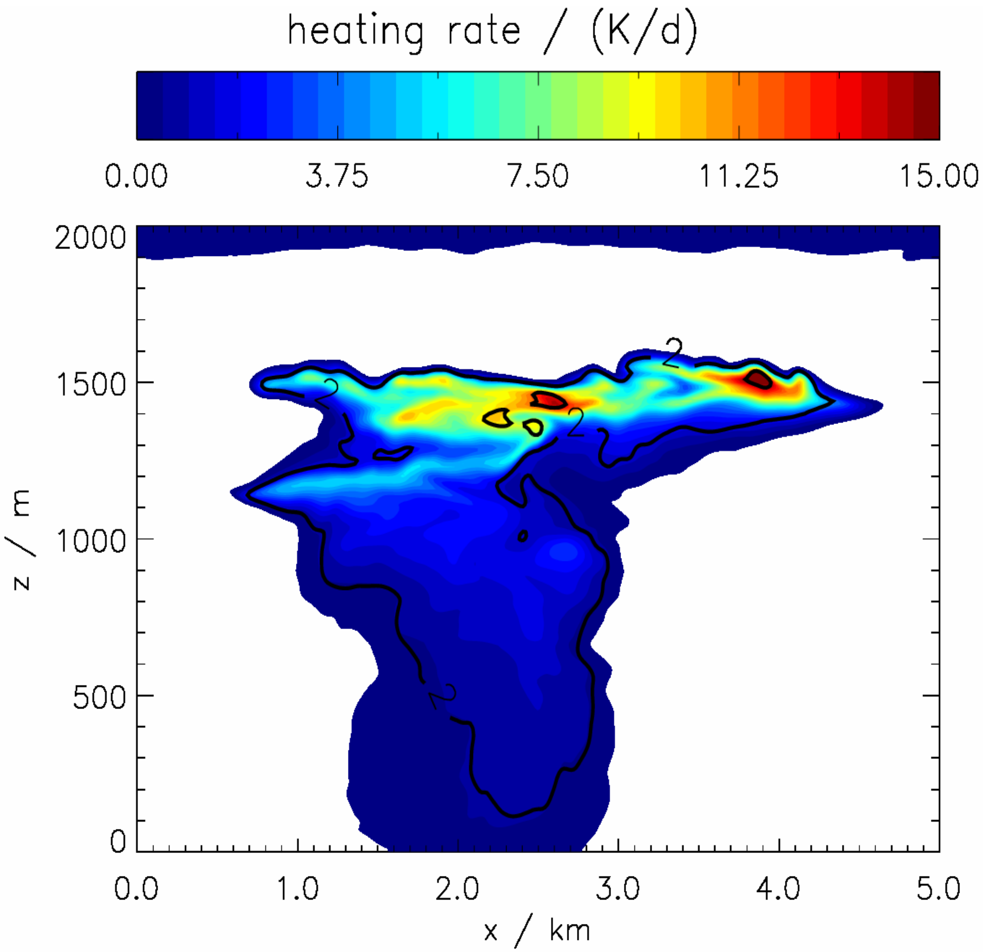
… stratification

Given in terms of N_{BV}

$N_{BV} = 0.5 \times 10^{-2} s^{-1}$
$0.7 \times 10^{-2} s^{-1}$
$1.0 \times 10^{-2} s^{-1}$
$1.3 \times 10^{-2} s^{-1}$
$2.0 \times 10^{-2} s^{-1}$

Heating rate inside the contrail

- Cloudless summer day
- $N_{BV} = 10^{-2}s^{-1}$, T = 217K
- $RH_i = 120\%$, $s = 0s^{-1}$
- Taken at t = 6500s
- Flight altitude z = 1300m

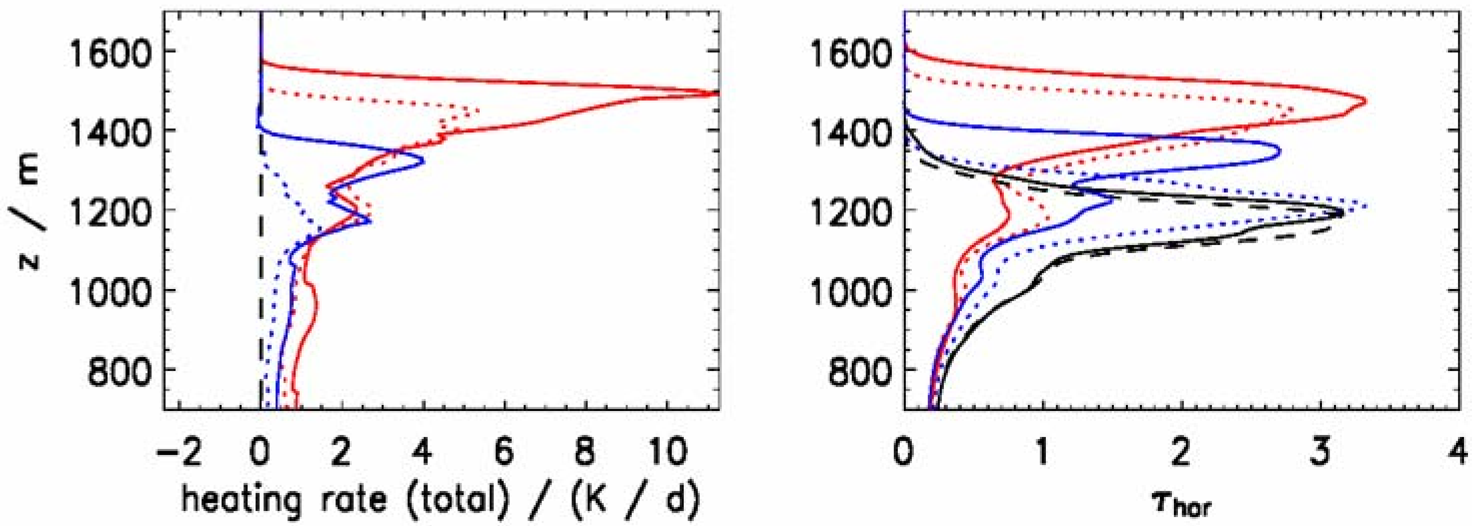


Radiation scenario I: Vertical displacement

- Reference run with no radiation (black)
- Color denotes season (summer, winter)
- Line style denotes time of day (Day: solid, Night: dotted)
- All cases without lower-level water cloud

Summer
Winter
Day
Night

$N_{BV} = 10^{-2}s^{-1}$
T = 217K
$RH_i = 120\%$
$s = 0s^{-1}$
Taken at t = 6500s
Flight altitude z = 1300m



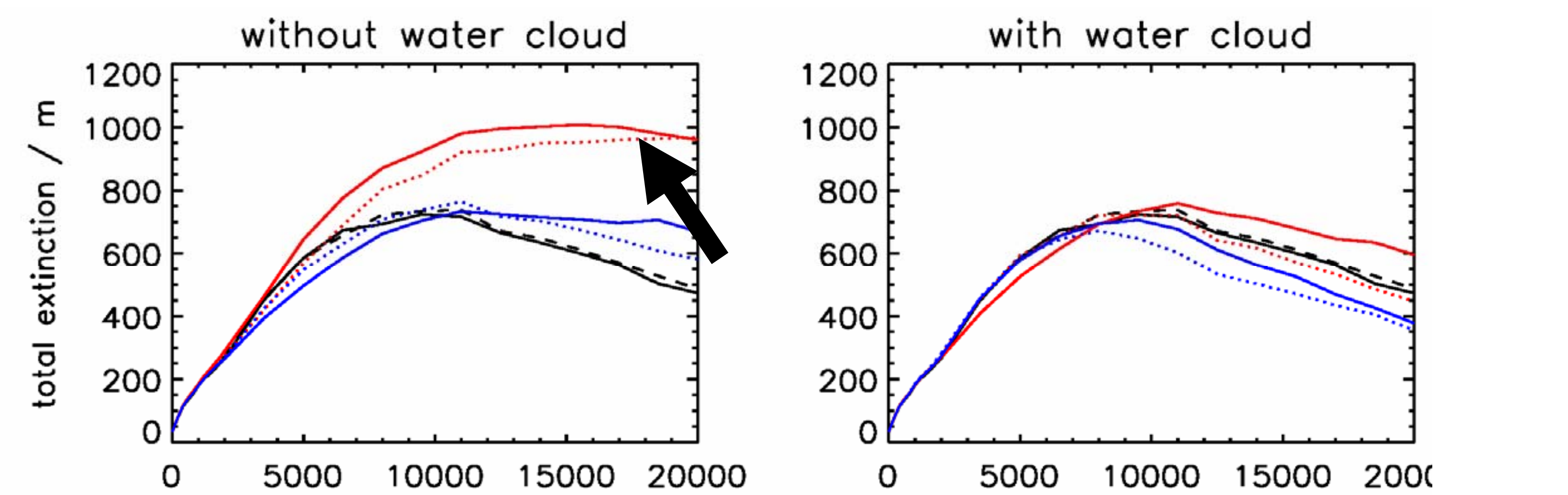
Radiation scenario II: Impact on contrail properties

Study total extinction E ≈
characteristic optical depth × characteristic width

$$E = \int (1-e^{-\tau})\,dx \approx \int (1-(1-\tau))\,dx = \int \tau\,dx = \iint \chi\,dx\,dz = \tilde{\tau} \times \tilde{B}$$

optical depth τ, extinction χ, characteristic optical depth $\tilde{\tau}$ and width $\tilde{B}$

$N_{BV} = 10^{-2}s$
$T = 217K$
$RH_i = 120\%$
$s = 0s^{-1}$

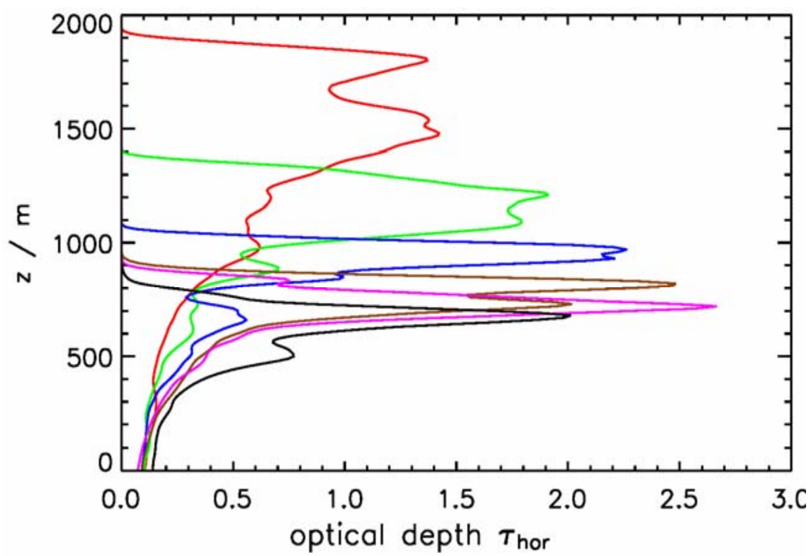


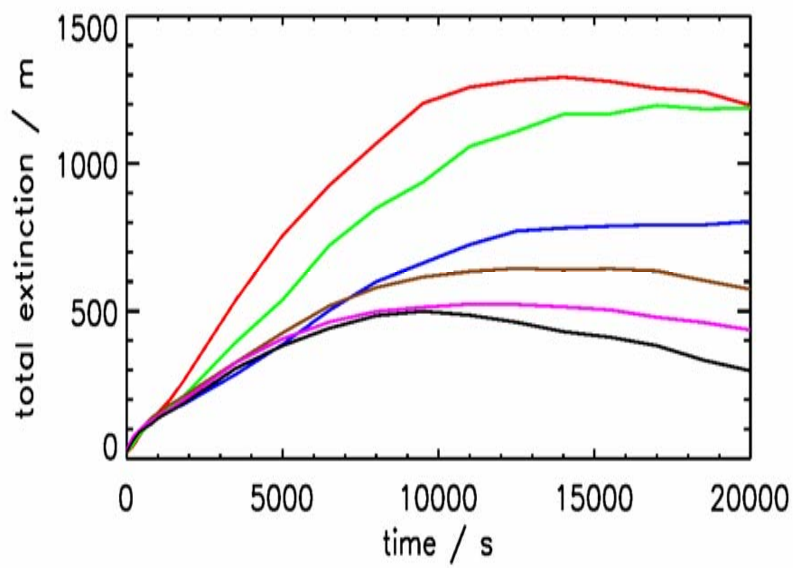
Radiation can prolong the contrail's life time

Stratification: Vertical displacement and contrail evolution

- Reference run without radiation: black
- Runs with radiation:
  N_{BV} = 0.5, 0.7, 1.0, 1.3, 2.0 x $10^{-2}s^{-1}$

Cloudless summer day
T = 217K
RHi = 120%
s = 0s-1
Taken at t = 6500s
Flight altitude z = 800m





Summary

- The radiation impact depends on the radiation scenario and the stratification
- Radiative impact small when a lower-level water cloud is present
- Radiative impact largest during summer (esp. during the day) and generally stronger at day than night
- Radiation scenario: Strongest sensitivity to lower-level cloudiness, followed by season and time of day
- At the standard $N_{BV}=10^{-2}s^{-1}$, the radiation impact is substantial only for $RH_i>120\%$, at smaller N_{BV} the threshold humidity is lower.
- In weakly stable atmospheres contrails can rise by more than 1km
- Radiative impact gets stronger with increasing temperature (the reduced temperature difference between contrail and earth surface is a second order effect)
- Ground-based observations of contrails, only if no lower-level clouds are present. Sampling biased to longer-living contrail
- Stuber study on contrail radiative contrail forcing assumed constant contrail properties. If one included the radiation effect, the RF contribution of night time contrails might be reduced slightly.
- The model suggest that the radiation-induced uplift doesn’t support secondary nucleation for most atmospheric conditions

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References

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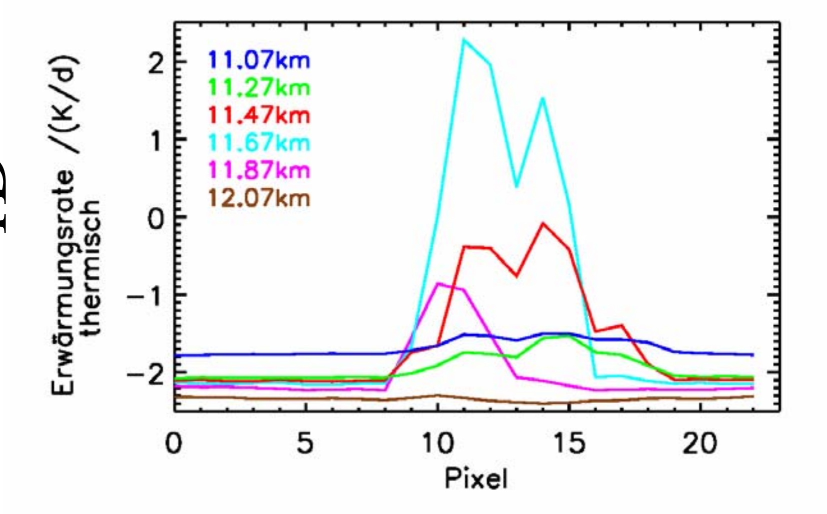
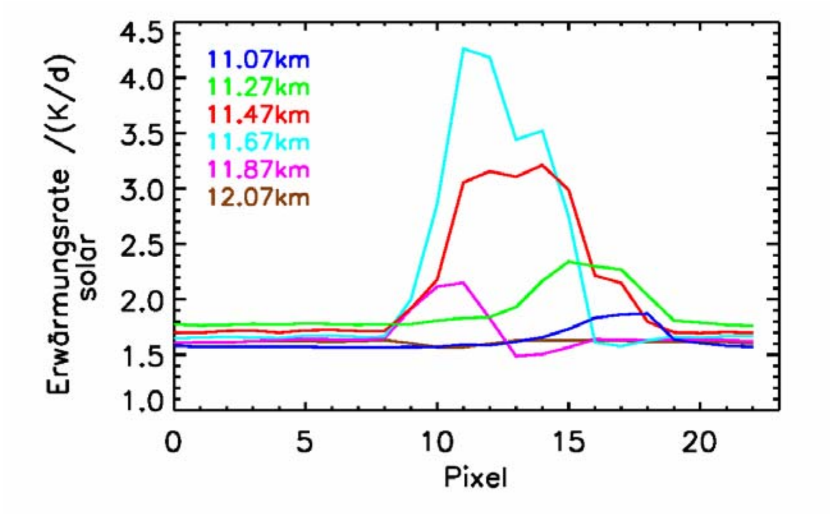
S. Unterstrasser, K. Gierens, *submitted to ACPD*: Numerical Simulations of Contrail-to-cirrus transition. Part 2: The impact of initial ice crystal number, radiation, stratification, secondary nucleation and layer depth

Comparison 1D-3D radiation routine

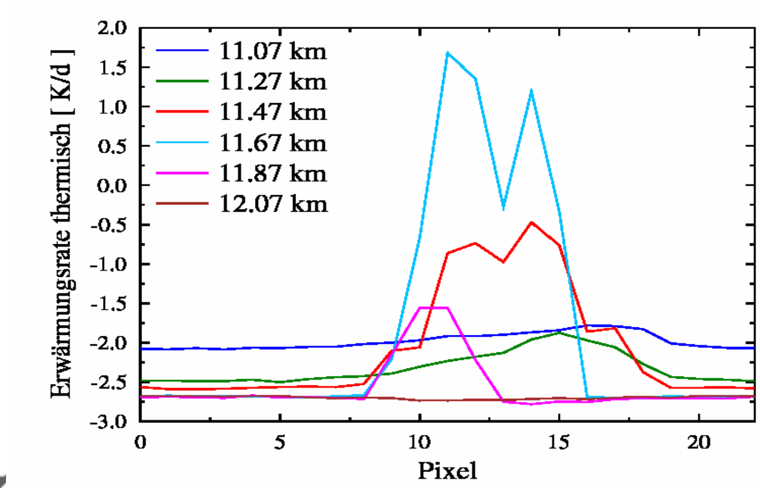
Thermal | Solar

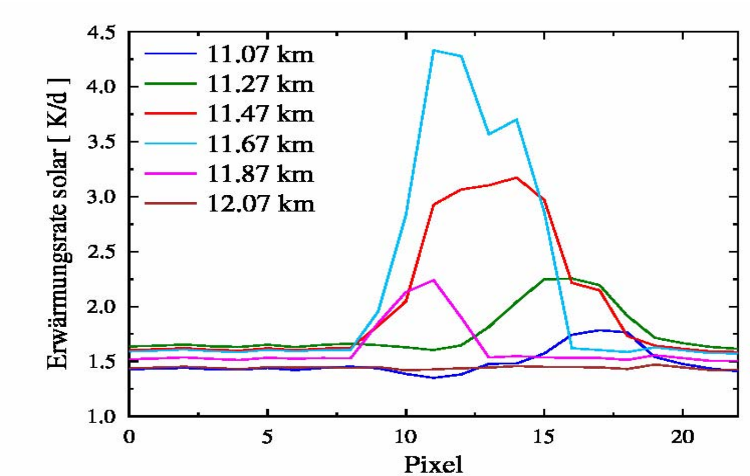
1D





3D





3D Simulations by C. Emde